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Nuclear and Radiation Physics

Elixir Nuclear & Radiation Phys. 76 (2014) 28275-28280

ISSN: 2229-712X

# Measurement of radioactivity in soil samples in selected areas of Kibwezi district, Kenya

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**ARTICLE INFO**

**Article history:**
Received: 21 September 2014;
Received in revised form:
25 October 2014;
Accepted: 4 November 2014;

**Keywords**
Absorbed dose rate,
Activity concentrations,
Effective dose.

**ABSTRACT**
The averages concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ measured in the samples collected in this study are 130.6±38.7 $BqKg^{-1}$, 137.9±39.7 $BqKg^{-1}$ and 1120.1±245.2 $BqKg^{-1}$ respectively. The absorbed dose rate in air at a height of 1m above the ground surface was estimated. The calculated radiation absorbed dose ranges from 95.4±3.2 $nGyh^{-1}$ to 300.4±5.5$nGyh^{-1}$ with an average of 193.2±44.5 $nGyh^{-1}$ .The effective dose rates were calculated for human exposure to the gamma radiations and were found to be in the range (0.23±0.01- 0.74±0.02) mSv $y^{-1}$, which is below the ICRP limit of 1 mSv $y^{-1}$ for members of the general public.



## Introduction

The aims of radiometric data measurements cover many different scientific and practical interests, ranging from basic geophysics to mineral exploration and environmental radiation monitoring. Accumulation of radioactive substances in the surface environment raises many problems concerning safety of biotic life, food chain and ultimately humans. To address these problems, assessment of radioactivity concentration in the environment is essential. It is necessary to quantify the distribution of radionuclides in the soil and rock samples and to assess radiological impacts of the detected radionuclides on human health. Among the rock constituent minerals are some natural radionuclidesthat contribute to ionizing radiation exposure on Earth. Natural radioactivity in soils comes from $^{238}U$ and $^{232}Th$ series and natural $^{40}K$. The distribution of these radionuclides has proved to be important in studies such as those on estimates of the level of that contributes to ionizing radiation exposure on Earth. Natural radioactivity in soils comes from $^{238}U$ and $^{232}Th$ series and natural $^{40}K$. The distribution of these radionuclides has proved to be important in studies such as those on estimates of the level of natural background radiation to which humans are exposed [14]. The study of the distribution of primordial radionuclides allows the understanding of the radiological implication of these elements due to the gamma-ray exposure of the body and irradiation of lung tissue from inhalation of radon and its daughters [3]. During the last few decades, Kibwezi district in Kenya has experienced intense developments in industry, tourism, transport, urbanization and horticulture. This paper reports the activity concentrations of natural radionuclides $^{238}U$, $^{232}Th$ and $^{40}K$, for soil samples from selected areas in Kibwezi district, Kenya. The objective of this paper is to evaluate the radiological hazards due to natural radioactivity associated with soil samples by calculating the absorbed dose rate, annual effective dose rate and external hazard index.

## Radioactivity in the Environment

Living and non-living things are exposed to radiation from different natural and artificial sources. The main components of natural sources are cosmic rays and primordial radionuclides such as $^{40}K$, $^{232}Th$ and $^{238}U$ which are present in the environment. Artificially produced radionuclides emanate from atmospheric nuclear weapons testing, accidental and routine emissions from nuclear activities [17]. Once present in the environment, these radionuclides are available for uptake by crops and animals and so make their way into the food chain.

## Natural Radioactivity

Natural radioactivity in the environment has two principal components, cosmic and primordial. Cosmic rays, originating in outer space, strike the earth's atmosphere generating a cascade of ionising particles. The interaction between cosmic radiation and atoms in the earth's atmosphere produces a range of cosmogenic radionuclides including beryllium-7 and hydrogen-3 (tritium). The short-lived primordial radionuclides are thought to have decayed leaving the long-lived ones, like $^{238}U$, $^{232}Th$, $^{87}Rb$ and $^{40}K$, which are significant components of the natural background radiation [4]. The most significant contribution to human exposure due to primordial radioactivity comes from radon, which is a naturally occurring gas produced as a result of the decay of uranium present in rocks and soil. Because radon is a gas it can seep up from the ground and may accumulate in buildings giving rise to human exposure [3]. Potassium-40, a naturally occurring radionuclide, is present in relatively large activity concentrations in the environment. However, it is controlled by homeostatic processes in the human body which means its equilibrium activity concentration is normally independent of the amount consumed [5]. Therefore, while the activity concentrations of this radionuclide in food are considerably higher than many other natural radionuclides, its presence does not result in an increased radiological hazard.

## Methodologies

### Sample collection and preparation

Soil samples were collected from various locations in Kibwezi district. A total of 30 soil samples were collected for the measurements of activity concentrations. Sampling areas was distributed across the entire Kibwezi district. "Figure 1" shows the sampling map. The soil samples were picked from wastes at quarries, scooped at various sites including farmlands, sand mines and surrounding hills. At each sampling point

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vegetation and debris were first removed to expose the soil. Soil was then collected at a depth of 20-25cm. The soil samples, each about 0.6 kg in weight, were dried in an oven at about 80°C for 24 hours to ensure that moisture is completely removed; the samples were crushed and sieved through a 200 µm mesh. Each sample (600 g) was placed in a plastic container, sealed and stored for 28 days. The storage allows for $^{238}$U and $^{232}$Th to reach secular equilibrium with their radionuclide daughters before measurement of radioactivity [14]

**Experimental Technique**

The concentration of the natural radioactivity ($^{238}$U, $^{232}$Th and $^{40}$K) in the soil samples, were measured using the gamma ray spectrometer in the Laboratory of Physics Kenyatta University, Kenya. NaI(TI) crystal detector of size 3"×3" combined with 8K multi channel analyzer. The technique used for measurement is a direct ɣ-counting method. The counting time fixed for each sample was 30,000 seconds. System calibration was done using three standard materials, obtained from International Atomic Energy Agency. The standards are RGU-1 and RGTH-1 and RGK-1, for uranium, thorium and potassium respectively [19]. The activities of the standards are 4900 Bq/kg for RGU-1, 3280 Bq/kg for RGTH-1 and 13400 Bq/kg for RGK-1. In addition to these standard materials, another standard referred as RGMIX, which is a combination of $^{238}$U, $^{232}$Th and $^{40}$K was also used.

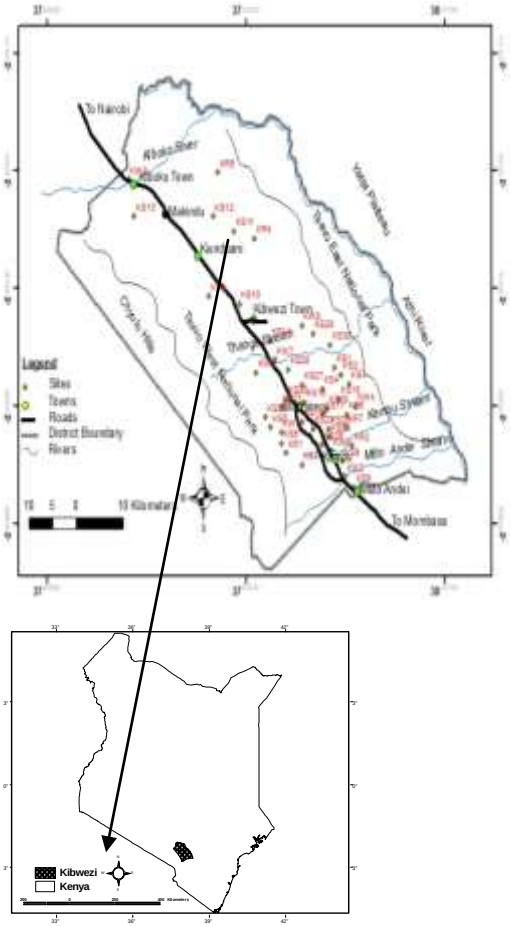


**Figure 1. Sampling Map of Kibwezi District**

**Results And Discussion**

The activity concentration (in Bq Kg$^{-1}$) of $^{238}$U, $^{232}$Th and $^{40}$K in the soil samples (KB S01- KB S30) were analyzed and the activity values obtained in this study are given in "tables 1". It may be seen from the table for soil samples that, the values of $^{238}$U has been found to be varying from 52.8±7.1 Bqkg$^{-1}$ to 228.7±5.2 Bqkg$^{-1}$. The activity concentration of $^{232}$Th varies from 57.6±9.6 Bqkg$^{-1}$ to 219.6±11.4Bqkg$^{-1}$. The activity concentration of $^{40}$K varies from 696.1±9.2 Bqkg$^{-1}$ to 1595.0±14.4 Bqkg$^{-1}$ .The average concentrations of $^{238}$U, $^{232}$Th and $^{40}$K in the soil samples are 130.6±38.7 Bqkg$^{-1}$, 137.9±39.7 Bqkg$^{-1}$ and 1120.1±245.2 Bqkg$^{-1}$ respectively. It is observed that the activity concentrations are above the world population weighted average of 33 Bqkg$^{-1}$ for $^{238}$U, 45 Bqkg$^{-1}$ for $^{232}$Th and 420 Bqkg$^{-1}$ for $^{40}$K as reported in "[17]". "Table 2" shows thorium uranium ratio while "table 3" shows the average activity concentrations of radionuclides in soils from Kibwezi district compared to values obtained from other parts in Kenya.

It is further observed that the activity concentrations of the $^{40}$K radionuclides are higher in Kibwezi district as compared to other parts in Kenya ([12],[7],[10] and[13]). Th/U ratio is greater than unity in most samples. This can be explained by high solubility of uranium ions compared to thorium ions.

The Th/U ratio in almost all samples is close to one .The Th/U ratio range from 0.46 to 1.75. Differences in thorium and uranium contents in soil can be attributed to high solubility of $U^{+6}$ whereas thorium ions are less soluble. "Figure 2" shows Average activity concentration of $^{238}$U, $^{232}$Th and $^{40}$ K in soil samples.

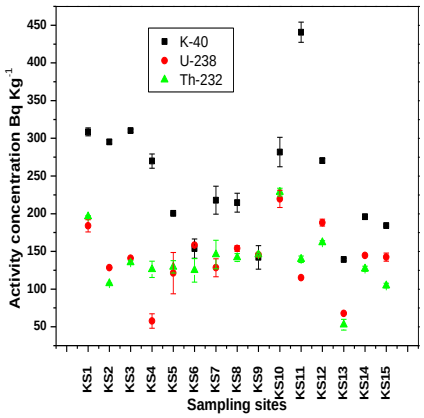


**Figure 2. Average activity concentration of $^{238}$U, $^{232}$Th and $^{40}$ K in the soil samples(K values have been divided by 3).**

The outdoor absorbed gamma dose rates in air at a height of 1m above the ground surface was computed based on the guidelines provided by [17]. The absorbed dose rate was calculated in this study using the formula obtained from [1].

$$D=\Sigma A_{Ei}C_F \quad (3.1)$$

Where, D, $A_{Ei}$ and $C_F$ are dose rate, activity concentration and dose conversion factor respectively. The conversion factors used in this study correspond to 0.621 nGyh$^{-1}$, 0.462 nGyh$^{-1}$ and 0.0414 nGyh$^{-1}$ for $^{232}$Th, $^{238}$U and $^{40}$K respectively [2].Therefore

$$D=0.621A_{Th}+0.462A_U+0.0414A_K \quad (3.2)$$

Where $A_{Th}$ ,$A_U$ and $A_K$ are average activity concentrations of for $^{232}$Th, $^{238}$U and $^{40}$K respectively. To estimate the annual effective dose, the conversion factor from absorbed dose in air to effective dose and the outdoor occupancy were taken into account. In the recent "[16]" report, a value of 0.7 SvGy$^{-1}$ was used for conversion factor from absorbed dose in air to effective dose received by adults. In this work this coefficient (0.7 SvGy$^{-1}$) and an outdoor occupancy of 0.4 were used. The following formula was used to determine the annual effective dose [15].

$$H_{R=}D_RTf_c \quad (3.3)$$

Where $H_R$ ,$D_R$ ,T and $f_c$ are effective annual dose rate in mSvy$^{-1}$, absorbed dose rate in nGyh$^{-1}$ the outdoor occupancy time and conversion factor respectively. Dose to risk conversion was done using the relation [9]

**Table 1.The Specific activities of the radionuclides in the soil samples (Bq/Kg)**

| Activity concentration Bq Kg $^{-1}$ | | | |
|---|---|---|---|
| **sample** | **$^{40}$K** | **$^{232}$Th** | **U** |
| KB S01 | 1542.5±26.5 | 183.9±8.1 | 196.1±1.4 |
| KB S02 | 1476.1±14.1 | 128.3±0.2 | 107.5±0.6 |
| KB S03 | 1550.5±10.6 | 140.9±0.5 | 135.4±2.3 |
| KB S04 | 1348.9±47.6 | 57.6±9.6 | 126.1±10.8 |
| KB S05 | 1001.3±3.9 | 121.2±27.3 | 129.5±8.3 |
| KB S06 | 768.9±63.7 | 158.5±1.4 | 124.9±15.6 |
| KB S07 | 1089.5±92.5 | 128.3±11.9 | 145.9±18.9 |
| KB S08 | 1073.2±62.1 | 153.9±3.8 | 141.9±5.2 |
| KB S09 | 710.7±77.9 | 145.6±1.8 | 145.9±1.9 |
| KB S10 | 1408.9±97.2 | 219.6±11.4 | 228.7±5.2 |
| KB S11 | 1595.0±14.4 | 115.1±0.4 | 139.6±4.2 |
| KB S12 | 1351.6±15.3 | 188.2±4.5 | 161.8±2.4 |
| KB S13 | 696.1±9.2 | 67.8±0.6 | 52.8±7.1 |
| KB S14 | 979.7±0.6 | 144.7±0.7 | 126.9±3.4 |
| KB S15 | 920.3±5.1 | 142.5±5.4 | 104.7±3 |
| KB S16 | 1278.7±2.4 | 187.4±12.3 | 175.8±6.7 |
| KB S17 | 952.7±4.1 | 67.8±0.8 | 101.9±4.7 |
| KB S18 | 992.6±3.3 | 200.8±10.6 | 118.3±6.8 |
| KB S19 | 1279.5±2.3 | 134.5±0.4 | 112.6±4.1 |
| KBS20 | 1033.2±27.1 | 145.3±3.9 | 160.3±0.3 |
| KB S21 | 1063.1±6.8 | 87.1±5.4 | 98.2±1.4 |
| KB S22 | 1087.7±7.5 | 139.8±2.3 | 98.5±2.1 |
| KB S23 | 1165.5±0.2 | 165.1±4.8 | 168.4±7.6 |
| KB S24 | 1070.1±0.9 | 84.6±0.3 | 67.6±3.8 |
| KB S25 | 1190.6±19.1 | 176.4±1.5 | 144.8±8.3 |
| KB S26 | 1087.3±9.5 | 132.9±4.6 | 163.5±1.5 |
| KB S27 | 735.7±2.4 | 100.8±0.4 | 82.9±6.6 |
| KB S28 | 967.1±30.1 | 151.6±0.5 | 86.7±2.5 |
| KB S29 | 1083.6±2.8 | 150.1±0.7 | 175.4±2.9 |
| KB S30 | 1102.6±5.1 | 119.1±0.8 | 95.1±5.3 |

**Table 2.Thoriu /Uranium ratio in samples**

| Activity concentration Bq Kg $^{-1}$ | | | |
|---|---|---|---|
| | **$^{238}$U** | **$^{232}$Th** | **Th/U** |
| KB S01 | 196.1±1.4 | 183.9±8.1 | 0.94 |
| KB S02 | 107.5±0.6 | 128.3±0.2 | 1.19 |
| KB S03 | 135.4±2.3 | 140.9±0.5 | 1.04 |
| KB S04 | 126.1±10.8 | 57.6±9.6 | 0.46 |
| KB S05 | 129.5±8.3 | 121.2±27.3 | 0.94 |
| KB S06 | 124.9±15.6 | 158.5±1.4 | 1.27 |
| KB S07 | 145.9±18.9 | 128.3±11.9 | 0.88 |
| KB S08 | 141.9±5.2 | 153.9±3.8 | 1.08 |
| KB S09 | 145.9±1.9 | 145.6±1.8 | 0.99 |
| KB S10 | 228.7±5.2 | 219.6±11.4 | 0.96 |
| KB S11 | 139.6±4.2 | 115.1±0.4 | 0.82 |
| KB S12 | 161.8±2.4 | 188.2±4.5 | 1.16 |
| KB S13 | 52.8±7.1 | 67.8±0.6 | 1.28 |
| KB S14 | 126.9±3.4 | 144.7±0.7 | 1.14 |
| KB S15 | 104.7±3 | 142.5±5.4 | 1.36 |
| KB S16 | 175.8±6.7 | 187.4±12.3 | 1.07 |
| KB S17 | 101.9±4.7 | 67.8±0.8 | 0.67 |
| KB S18 | 118.3±6.8 | 200.8±10.6 | 1.7 |
| KB S19 | 112.6±4.1 | 134.5±0.4 | 1.19 |
| KBS20 | 160.3±0.3 | 145.3±3.9 | 0.91 |
| KB S21 | 98.2±1.4 | 87.1±5.4 | 0.89 |
| KB S22 | 98.5±2.1 | 139.8±2.3 | 1.42 |
| KB S23 | 168.4±7.6 | 165.1±4.8 | 0.98 |
| KB S24 | 67.6±3.8 | 84.6±0.3 | 1.25 |
| KB S25 | 144.8±8.3 | 176.4±1.5 | 1.22 |
| KB S26 | 163.5±1.5 | 132.9±4.6 | 0.81 |
| KB S27 | 82.9±6.6 | 100.8±0.4 | 1.22 |
| KB S28 | 86.7±2.5 | 151.6±0.5 | 1.75 |
| KB S29 | 175.4±2.9 | 150.1±0.7 | 0.86 |
| KB S30 | 95.1±5.3 | 119.1±0.8 | 1.25 |

**Table 3. Average activity concentrations of radionuclides in soils from Kibwezi district compared to values obtained from other parts in Kenya**

| Place /Author | Activity Concentration (Bqkg$^{-1}$) | | |
|---|---|---|---|
| | $^{238}$U | $^{232}$Th | $^{40}$K |
| Kibwezi District (This work | 130.6±38.7 (52.8-228.7) | 137.9±39.7 (57.6-219.6) | 1120.1±245.2 (696.1-1595.0) |
| Mrima hill (Kebwaro,2009) | 207.03±11.3 (67.0 – 354.3) | 500.7±20.3 (298.2 – 869.0) | 805.38±20.7 ( 506.5 – 1108.2) |
| Kwale T. Mines (Osoro, 2007) | 20.9± 7.6 (7.4 – 40.6 ) | 27.6± 9.1 (8.4 – 43.6) | 69.5± 16.5 (31.9 – 114.1) |
| Mombasa (Hashim *et al*., 2004) | 22.8±1.8 (14.4 – 33.3) | 26.2± 1.7 (16.7 – 35.2) | 479.8±24.2 (372.5 – 648.2) |
| Malindi (Hashim *et al*., 2004) | 21.3 ± 3 (16.4 – 40.2) | 19.1 ± 3.5 (11.3 – 39.9) | 519.2 ± 42.1 (128.7 – 898.5) |
| Gazi (Hashim *et al*., 2004) | 11.9 ± 1.4 ( 5.0 – 19.8) | 10.8± 1.0 ( 5.4 – 17.4 ) | 206.1± 26.4 ( 125.6 – 346.0 ) |
| Different parts in Kenya (Mustapha *et al*.,1997) | 28.7± 3.6 ( 9.8 – 93.0 ) | 73.3± 9.1 (5.0 – 165.7) | 255.7 ± 38.5 (53.1 – 802.0) |

**Table 4. Absorbed dose rate and corresponding annual effective dose**

| Sample | *Absorbed dose nGyh$^{-1}$* | *Annual effective dose rate (mSvy$^{-1}$)* |
|---|---|---|
| KB S01 | 268.6±5.5 | 0.66±0.01 |
| KB S02 | 190.4±1.0 | 0.47±0.00 |
| KB S03 | 214.2±0.3 | 0.53±0.00 |
| KB S04 | 149.9±2.9 | 0.37±0.00 |
| KB S05 | 176.5±12.9 | 0.43±0.03 |
| KB S06 | 187.9±8.9 | 0.46±0.02 |
| KB S07 | 192.2±12.3 | 0.47±0.03 |
| KB S08 | 205.6±2.6 | 0.51±0.01 |
| KB S09 | 187.3±5.2 | 0.46±0.01 |
| KB S10 | 300.4±5.5 | 0.74±0.02 |
| KB S11 | 227.2±4.9 | 0.56±0.01 |
| KB S12 | 247.6±2.3 | 0.61±0.01 |
| KB S13 | 95.4±3.2 | 0.23±0.01 |
| KB S14 | 189±2.0 | 0.46±0.01 |
| KBS15 | 175±4.6 | 0.43±0.01 |
| KB S16 | 250.5±4.5 | 0.61±0.01 |
| KB S17 | 128.7±2.5 | 0.32±0.01 |
| KB S18 | 220.5±3.3 | 0.54±0.01 |
| KB S19 | 188.5±2.2 | 0.46±0.01 |
| KB S20 | 207.1±3.5 | 0.51±0.01 |
| KB S01 | 143.5±4.3 | 0.35±0.01 |
| KZ S22 | 177.4±0.2 | 0.44±0.00 |
| KB S23 | 228.6±0.6 | 0.56±0.00 |
| KB S24 | 128.1±1.6 | 0.31±0.00 |
| KB S25 | 225.7±3.7 | 0.55±0.01 |
| KB S26 | 203.1±3.9 | 0.50±0.01 |
| KB S27 | 131.4±2.9 | 0.32±0.01 |
| KB S28 | 174.2±2.7 | 0.43±0.01 |
| KB S29 | 219.1±0.8 | 0.54±0.00 |
| KB S30 | 163.5±3.1 | 0.40±0.01 |

$$G = fHP \qquad (3.4)$$

where G, f, H and P are estimated number of casualties, dose to risk conversion factor, annual effective dose and the total population respectively. A dose to risk conversion factor of 5% per Sievert [8] to the maximum effective dose observed in this study was applied. Effective dose rates in the samples is shown in "figure 3".

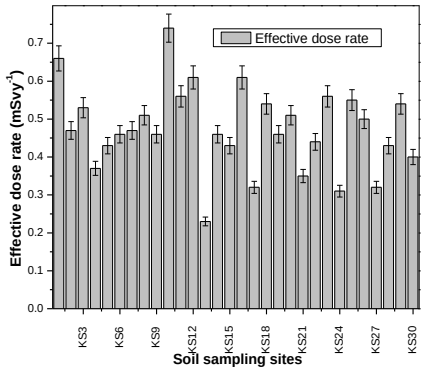


**Figure 3. Effective dose rates versus soil sampling sites**

The estimated results for absorbed dose rate and corresponding annual effective dose rates for soil samples are tabulated in tables 4. The absorbed dose rate in air at a height of 1m above the ground level obtained from the different sampling points ranged from 95.4±3.2 $nGyh^{-1}$ to 300.4±5.5 $nGyh^{-1}$ with an average of 193.2±44.5 $nGyh^{-1}$. This value is higher than the worldwide average of 60 $nGyh^{-1}$ [16]. The annual outdoor effective dose ranged from 0.23±0.01$mSvy^{-1}$ to 0.74±0.02$mSvy^{-1}$ with an average of 0.48$mSvy^{-1}$.Absorbed dose rates for soil samples are shown in "figures 4". Dose to risk conversion was done using the relation "(3.4)". For a sample population of 229,000 people in Kibwezi district and the maximum annual effective dose rate of 0.74$mSvy^{-1}$ the number of exposure induced deaths per year was estimated to be between 8 and 9 people. However the value of DRCF varies with age, sex and sensitivity to radiation –induced cancer of the individuals exposed to the radiation [18].

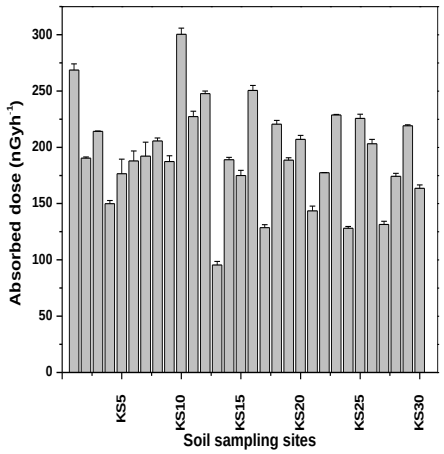


**Figure 4. Absorbed dose rates versus soil sampling sites**

**Conclusion**

The specific activity concentrations of the three radionuclides $^{238}U$, $^{232}Th$ and $^{40}K$ in the soil samples analysed were found to be in the range of (52.8±7.1 -228.7±5.2) $BqKg^{-1}$, (57.6±9.6-219.6±11.4) $BqKg^{-1}$ and (696.1±9.2 -1595.0±14.4) $BqKg^{-1}$ respectively. The averages concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ measured in the samples collected in this study are 130.6±38.7 $BqKg^{-1}$, 137.9±39.7 $BqKg^{-1}$ and 1120.1±245.2 $BqKg^{-1}$ respectively. These values are higher than those reported by other researchers in other parts of the country ([12],[7] and[13]). However these values are below the range observed by other researchers in regions of high natural background ([14],[11]and [10]).

The effective dose rate due to gamma radiation from the decay of $^{238}U$, $^{232}Th$ and $^{40}K$ in soil samples were found to be in the range of (0.23±0.01- 0.74±0.02) mSv $y^{-1}$ with a mean of 0.48±0.11$mSvy^{-1}$. Some sampling points registered an effective dose rate values above the global average value of 0.48$mSv^{y-1}$, however the mean value was the same as the global average value of 0.48$mSvy^{-1}$ [16]. The effective dose rate is also slightly below the ICRP limit of 1$mSvy^{-1}$ for members of the general public [8].Therefore this area may not pose radiological risks to the inhabitants owing to the harmful effects of ionising radiation from the Naturally occurring radioactive materials in the soil.

The calculated radiation absorbed dose from the different sampling points, ranges from 95.4±3.2 $nGyh^{-1}$ to 300.4±5.5$nGyh^{-1}$ with an average of 193.2±44.5 $nGyh^{-1}$. The mean value is higher than the worldwide average of 60 $nGyh^{-1}$.

Applying the dose to risk conversion factor of 5% per Sievert [8] to the maximum effective dose of 0.74mSv observed in this study it can be concluded that; for an estimated population of 229,000 people exposed to the gamma radiation from the surface soils, the risk causalities per year may be between 8 and 9 people. However it is important to note that dose to risk conversion factor depends on other factors also, for example the sensitivity of the individuals to radiation induced cancer.

**Acknowledgment**

The authors would like to thank Kenyatta University and the University of Nairobi for Providing equipment and materials for this research.

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